

THE AGE OF THE EARTH FROM THE PALEONTOLOGICAL VIEWPOINT.

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It falls to me to consider this knotty problem on the basis of the biological evidence alone, in so far as it is possible to disentangle this from its almost inevitable complication with geological accompaniments. In saying biological I mean, of course, biology with the time element generously admitted; that is, not the biology of the instant, the present, but the long biological panorama leading up to the present. Thus I am in a different case to some of my colleagues, for I presume it safe to say that life can have come into being only as a secondary potency in the evolution of force. Just what I mean is that the combination or interaction of physical energies of different categories did not produce the form of energy we designate as life till after a very long chapter of the earth's planetary history had been written. I may as well frankly say at the beginning that there can be little hope of arriving either at a reliable or an approximate conclusion as to the age of the earth through this paleontological channel, unless the study of the chronological development of life may in some way afford a measure of the rate of vital processes and thus the measure of some short span or infinitesimal fraction of earth history. This is a shadowy road and this presentation must resolve itself into consideration of such evidences as there may be for time-requisites in the consummation of evolutionary biological procedures, whether in gross or in detail. The bare statement of this fact in such vague form must carry with it an indication of the grave uncertainty of the results except to minds of the fourth dimension. I am not convinced that it is within the power, now or ever, of even the most refined understanding of paleontology, to accomplish this and establish such standards of measurements. Nor am I at all confident that the attempts which have been made to establish such rates of procedure

could justify the great labor they have exacted, were it not for the important accessory facts they have elicited.

There seems to be no effective reason or very good philosophy in declaring, as some of our writers have been wont to do, that all life is one life. We seem to have really established the polyphylogeny of several races not only in the lower phyla of animals and plants, but among the vertebrates, and in the thought of competent authority, even to the inclusion of man, and we assign these like products to a differently governed and directed inheritance emanating from fixed points in evolutionary history. This is an enlarging point of view in the interpretation of past life, and admitting its general effectiveness we can conceive and can justify a concurrence of physical energies which need not, and indeed should not logically, be restricted to some single outburst and some single definite moment in earth history. This intimation is that life itself may be polygenetic, though we would not have it interpreted as applying to the reiterative appearance of inceptive life through the ages, which is an old conception that still awaits its justification; it is rather only the precise implication of a terrestrial condition so controlled that by the intersection of the requisite forces life came into being at the *points* rather than at the point of such intersection—a crude way of stating it, perhaps, but it is an intimation of my meaning.

When we gaze upon some of Walcott's Burgess Pass fossils, see the extraordinary intricacy of their anatomy, as, for example, the crustacean *Burgessia*, with not merely the delicately toughened parts of its exterior, but the evidence of internal organs of great refinement, the lobulation and venation of renal organs; and, in the trilobite *Neolenus*, the multiplex delicacy of gills and swimming or walking organs, the effective impression is that, as between such creatures and their nearest allies and perhaps their offshoots of to-day, there is no difference in degree of specialization of structure, no progress in perfection of organic function. Indeed, we may even go further; modern allies of these creatures are in close straits of adjustment to their own physical surroundings, which are too often indicative of the surrender of progress, and to this I shall again make reference. But the Walcott fossils are from the Middle Cambrian, almost the

oldest term in the whole long series of rocks in which life has been well preserved, and we here, in this year 1922 of the Christian era, are unable to find that any progress has been made in the structure of these creatures or along the direct line of their development and succession. Their successors in time and place have adjusted, readjusted, adapted, and readapted themselves without having produced a creature of their tribes which can be called a more intricate or a more perfect mechanism.

And yet what has gone on in that vast interval of time from then to now? The successive derivation of all intermediate types of life have come into being. The trilobite *Neolenus*, from the viewpoint of the paleontologist, stands for a tremendous conception of the vastness of time behind it. This inconspicuous thing, standing back behind us in the dim days of the Cambrian, stripped bare now by the arduous labors of its discoverer, reveals a creature so highly specialized that it must have commanded uncountable ages for its production by any such process of organic development as that to which we paleontologists make our allegiance. The problem behind the *Neolenus* is that of having developed out of the unicellular expression of life, under favoring physical conditions and directive impulse, this intricate and closely functioning organism. How long did it take? I would like to put the problem to the experimental biologist: Given an organism with a full equipment of motor and sensory nerves and an elaborated digestive tract, with specific organs of circulation, reproduction, and of waste—is the distance greater from that starting point to the specialized creatures of the present, ourselves if you will, or from the nuclear cell (which we must hold to be not alone the seat but the radial point of life) up to that marvelously specialized creature? Starts are slow, progress to be secure must be deliberate, the momentum of the impulse must be acquired gradually, the passage from a protozoan to a metazoan means the crossing of a deep moat, the climbing of a high wall. But the directive once acquired, then matters may go forward with acceleration. On the basis, then, of the structure of this ancient trilobite alone, it is safe and probably necessary to answer that *Neolenus* was farther away from the beginning of life, very, very much farther away, in the highest probability, than we of to-day are from *Neolenus*.

This is a relative expression, but we can not be more concrete. The Walcott discoveries have lifted the veil from a scene in the panorama of life that was barely guessed before. In our previous general understanding there was, in the still earlier faunas, a group of creatures believed to be of simple structure and lowly place in the category of life; it was thought that with these simple things the caravan of life had got under way for its journey through the ages; and now we are compelled to believe that the journey was half over when this caravan first came under our eye.

It is not my part to make a review of statements and calculations of earth age based on the rates of sedimentation from the Cambrian time on to the present; but whatever these are, they may, from the biological point of view, reasonably be doubled and then increased by some improper fraction, if we are to reach a competent expression of the duration of the life-day of extinct species—the *zoëhemera*, as I termed it many years ago, and of the sum of these which go to make a fraction of earth history.

It has not been the practice of students of evolutionary paleontology to raise the question as to whether there were time enough available for the production of the succession of results which pass under their eye. Such an attitude would of itself be highly unphilosophical, and only a natural inquisitiveness or curiosity quite unessential to the real philosophy of the succession and purpose of life has led to the occasional investigation as to the possible time-rate of evolutionary processes under historic and under natural conditions. We are not the makers, but the users, of time. There have been stages in the history of our science when we have been treated gingerly by astronomers and physicists in the allotment of time, but now that our colleagues in celestial mechanics are heaping upon us their munificence in the prescription of this heavenly commodity, we are content; and the interpreters of radio-chemistry—we thank them for giving us what we already had. There is time enough. So much, indeed, that to absorb a needful share of it into the philosophy of the evolution of life actually requires of us a revision of our conceptions.

I should, I think, take passing notice of the fact that the problem as to how species have originated, one from another, with or without

the help of mutations, variations, or variants, the problem of the factors which have controlled their production, does not belong to paleontology. Bateson, speaking recently at Toronto, has expressed the conviction that after the nearly three quarters century since the publication of Darwin's *Origin of Species* we are still in doubt and darkness as to the causes of the origin of species. Incautious as it seems, that expression would still be a hopeful one if it means that in this relatively brief period the study of this theme, stimulated by Darwin, has led to the elimination of an extensive array of supposed factors, so that if the buried treasure, if it is really the treasure he has thought, has not yet been found, at least some of the brush has been cleared away from about the place where it lies hid. Both laborers, those in the field of living nature and those delving among the past creation, see the engrossing fact of evolution, but see it out of different eyes; the former perhaps as one would see a vast throng gathered together to acclaim a momentous event, a great victory or a high armistice; the latter as an endless army marching by, its vanguard already out of sight in the mists of the horizon, stragglers along the way falling back or giving up in hopelessness, while the interminable procession ever emerges out of the shadow.

Once upon a time, when Walcott was first bringing out his wonderfully specialized Cambrian fossils from the Burgess shale, I said to the discoverer in a jocular way, "Keep on and you may find the remains of a Cambrian man." In the recent address referred to, Bateson ventures more solemnly into this field. "It has been asked [I am quoting] how do you know, for instance, that there were no mammals in paleozoic times? May there not have been mammals somewhere on the earth though no vestige of them has come down to us? We may feel confident there were no mammals then, but are we sure? In very ancient rocks most of the great orders of animals are represented. The absence of others might by no great stress of imagination be ascribed to accidental circumstances." Considering that these remarks were made in the presence of a great body of scientific men, among whom were paleontologists, I fear the speaker neglected to do what he should have done and as Artemas Ward was wont to do in like case, for in no evidence from any quarter, whether

it be of biology, geography, geology, meteorology, oceanography, or psychology, is there the slightest justification for seriously embalming such a fancy in a scientific address and sending it abroad in the world for the daws to peck at.

We must fasten our gaze upon such impressive evidence as can now be adduced of the duration of time required in the attainment of organic specializations, and let me supplement those I have given by others taken from the plant world. Casting up the evidences that have been adduced by paleontologists and paleobotanists, I think the footings show very positively a large balance of argument in favor of the great conception that the life of the land has emerged from the sea. I believe it may be said, on behalf of paleontologists generally and their broader deductions, that these are happy in the harmony of their conclusions in this matter after having experimented with and checked up alternate conceptions.

The broader lines of evolutionary derivation and the best weighed deductive propositions seem to intimate a convergence of the life lines back to the sea and a radiation from it. The inception of life was the most solemn moment in the history of the Universe. We invite certain astronomers to refrain from further speculations and presumptions as to life in other worlds, and followers of Arrhenius from pursuing life spores through interplanetary space. These notions seem to be very exciting to the emotional public and there is indeed no shred of evidence of these things, no matter what physical conditions may be predicated of other worlds than this. So far as the evidence of outstanding facts and major probabilities goes, Life is confined to the Earth. Into this solemn event, the birth of life, the interaction of the forces requisite to emergence, we shall not here attempt to pry. We look back, then, to a primitive period of life in the sea, the Plankton epoch, the place and stage of life's emergence, the surface life; followed by a Benthic epoch, the secondary stage of development in which the living forms had found the shallower sea bottoms and thereupon began their adaptations and more rapid evolution.

I shall now borrow freely the brilliant conceptions of Church, the British paleobotanist, as to the procedure among the plants thence-

forward from the sea to the land, an act which implies time in impressive measures and yet an act which we know has reversed itself in later geological times, at least among the animals, with nostalgic energy and must again and again have shown a like reversion in both the animal and in the plant world. We see suggestions of these reversionary movements among the Amphibia and the Mollusca and many Mammalia, and it seems highly probable that a more exact knowledge of extinct life will establish these suggestions and awaken others.

The Plankton epoch, says Church, gave rise to the first encysted flagellate plants which, under conditions of the Benthon, developed multicellular thallus, tissues and organs of special function and a reproductive mechanism contrived so as to minimize waste. Then followed the Epoch of the Land Flora brought on by the transmigration of highly developed algæ which in fact "appear to have been more highly organized than any single algal type at present known to exist in the sea." "The algæ of transmigration may be . . . said to have combined the best features of the known great conventional series of marine phyto-benthon." "The origins of all the main successful adaptations of the land are to be traced down to the benthic phase of the sea." In this impressive statement we are confronted by the quality of the plant life at its emergence from the sea.

Now as to the period of its emergence, of foremost importance to our present consideration; Thomas C. Chamberlin in 1913 directed attention to the fact that the Precambrian rock complex is divided into earlier and later stages on the basis of the degree of disintegration of the exposed rock surface. In the lower division there is an immature disintegration which implies partial decomposition, but the mature disintegration of the later division implies, he says, "some restraining agency that held the rock in place while the slow weathering completed its work." "This view favors the existence of a vegetal covering of the land as far back as this period."

Church, therefore, has a well-found argument when in the presence of this fact of precambrian weathering he intimates that it was with the uplifting and exposure of the primary rock to the air that

“the marine organism was brought into direct association with atmospheric air and subaërial environment to mark out new lines of progression to still higher and more strenuous forms of land life, though these are again necessarily expressed in terms of preceding organization and mechanism.” The point to be made here is that with the earliest lifting of land from the sea, benthic algæ of advanced structure, “the remarkable algæ of transmigration,” as he has characterized them, got their foothold on the land. “The Evolution of the Land Flora was a phase of transmigration in *situ*” and did not involve a preliminary landward migration by the way of fresh water, “the biological factors being exposure to more or less desiccation and the removal of the food solution.” “The few races that survived only did so by pressing to the utmost any principles of economy in reproductive output that they may have previously initiated,” such as oögamy and fertilization in *situ*.

The picture presented by this line of carefully founded reasoning is even more impressive in its demands upon time than the argument we have presented from animal life. It is summed up thus: Plants of complex organization and function—deductively of higher organization than can be to-day found among the algæ—had worked out their attainments before their arrival on the land, and probably this organic achievement, not surpassed in the seas of to-day, was accomplished at a stage in earth history long before the Cambrian Epoch brought with it the tangible evidence of the complex animals. The argument from the plants is more highly deductive than that from animals, but its steps are logically taken from effect to cause, and in its presence we must stand uncovered at the inconceivable lapses of earth-time through which these transmigrant plants were slowly working out their organization in the waters when there was no permanent land—a period of time which must have been longer than all time that has passed since the emergence of the Laurentian or the basal rock complex of the great shields of the earth.

II.

If we are prepared to concede the steadily increasing weight of evidence of the polyphyletic origin of genera which recent researches

have indicated for so many different groups of life, and can compel our conception to grasp the duration of the vast unrecorded past of life-history, there remains another phase of the paleontological record which in part emphasizes and in part serves as a check on this conception. It has fallen to me to study the earliest recorded expressions of dependent life—that is, the beginnings, so far as we can find them, of such consociations of animals as we are wont to designate as parasitic, mutualistic, and symbiotic, wherein one creation has depended upon or adjusted itself to the life functions or habits of another, or has sought mechanical protection at the cost of its own locomotive independence. Two very obvious facts seem to stand out as a result of these inquiries: (1) That these interdependent conditions with which the living world is rife to-day, in passing backward to the early stages of Paleozoic time, become palpably fewer; indeed, while such conditions are well marked in some groups and common in others during the middle and later Paleozoic, they are very unusual in the earlier stages and in the Cambrian fauna are little more than suggested. (2) This dependent state seems with reasonable clarity to be resolvable into an original loss of locomotive independence, a willingness to be fed rather than to feed, an adaptation to an easier mode of life. The commanding percentage of the Cambrian fauna belongs to groups against which the charge of surrender of locomotive independence can hardly be laid, though inclusive of groups of animals which in later stages did become infected with the loss of independence, but still in a capital sense embraced those whose independent living was unimpaired.

These considerations I have analyzed elsewhere in some detail and their significance is this—that the degeneration of life (for dependence of necessity implies degeneration of physiology) has been a process attendant upon and of course influencing evolution, but apparently limited in its effects to that part of the procession of life which comes under our actual observation; that is, since the days of the free and independent faunas of the Cambrian. If this is an approximation to the truth, as we believe it to be, then in a broad sense the real vigor of life, which established the major branches and laid down the plan of all future ages, was dominant in its purity in

the ages before the beginning of the life record in the rocks. How often the student of the past of the earth has exclaimed at the wonder that Man came through to his excellence, in a world permeated with ever-increasing conditions of degeneration.

III.

With such propositions as the foregoing we are confronted by an impressive requirement of time necessary to the development of life on the earth. It is a requirement that seems to roll back and ever backward into the undifferentiated ages of our planetary history. It is a magnitude that takes on proportions before which the outstanding estimates of time based on processes of rock building would seem to dwindle, and it partakes more and more of the magnitudes in which the radiologist has been wont to speak. The question for us now is whether our present knowledge affords any basis for an estimate or calculation of this time or any part thereof into a concrete expression. If it were possible to estimate by any or all approaches, the length of the life of a single extinct species in any part of the world, there would then lie a possibility of determining what fraction this given quantity might be of the whole. For more than two generations the evidence has been sought, paleontologists endeavoring first to establish the endurance of a given or index species as the basis of a geologic or stratigraphic element—a zone.

Into the discussion of the Zone—its meaning in time and space—has entered a very long list of eminent names in the science. The Zone has been looked upon as a sedimentary element in which a datum species slowly coming to its acme suddenly culminates and abruptly disappears; as such sedimentary unit in which not a species, but a mutation, or an entire fauna rises and falls. To Oppel the Zone was a space-unit. Buckman has embodied the time conception of the Zone in the word *hemera*. The double combination of time and space makes a *biozone*. The time unit has also been termed *sæculum* by Jukes-Brown, *moment* and *phase* by the International Geological Congress. In the recent summary of these expressions and their interpretations as given by Diener, in order to determine a proper basis for his discussion, he employs the term Zone for the spatial, that is

horizontal and vertical distribution of a fauna, whose time is a Moment.

The whole interpretation of these conceptions centers upon the origin and endurance of a mutation, which in the proper paleontological sense is a departure from a recognized species toward and into a unit which, by determinate action of the genes producing variation, will become another species. That is to say, the mutation is a clearly recognizable entity in paleontology, is the bridge crossing from species to species, the connecting link which establishes the continuity of the chain. Apart from considerations of physiology only, the paleontologist sees no further occasion for debating the existence of connecting links or of passages from species to species, or as to how species originate. The mutation is the departure from the one, seeking adjustment and failing, or seeking and finding it in what must be recognized from accepted standards as a distinct specific form, a different species from its parentage. But when it comes to a matter of determining the rates, the time measure of these changes under varying and all conceivable physical conditions, the pursuit seems to us hopeless, hopeless a priori, hopeless in observation. There are species that have held their own without change through the ages—"immortal types" they have been called; and there are others which have yielded so rapidly to change that their evolution is explosive. The same facts are true of *groups* of animals; and for the entire organic world there have been earth-wide periods of long stagnation as well as of rapid intensive change. So long as an estimate of the age of the earth rests on evidence of the rate of change or adjustment in organisms through the acquisition of new characters, we may as well abandon the attempt to express it in concrete terms and satisfy ourselves that for the development of life the duration of that fraction of the earth's history is beyond human expression.